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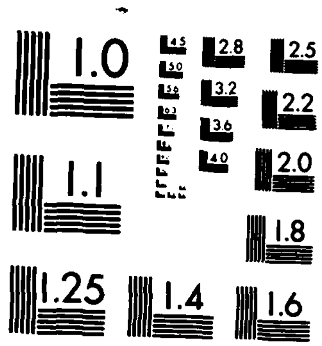

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A NOMOGRAPHIC PROCEDURE TO CALCULATE

POISSON EQUATION PARAMETERS

by
M. Rhoden
R. R. Radke

January 1982

U.S. ARMY MISSILE COMMAND

Redstone Arsenal, Alabama 35898

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A NOMOGRAPHIC PROCEDURE TO CALCULATE POISSON EQUATION PARAMETERS

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ABSTRACT

Nomographs and tables based on the Poisson Distribution are provided. The graphs give the mean time between faiures (MTBF) from test data at one sided confidence boundaries. Operating characteristic (O-C) curves for fixed time life test and fixed sample attribute test can be calculated.

ACKNOWLEDGEMENT

The authors want to thank Mr. Albert R. Maykurt and Francis A. Thiessen for their help in developing the nomographs.

LIST OF SYMBOLS

C	=	Confidence (1-Pa)
a	=	Parameter of Poisson Distribution
MTBF	=	Mean Time Between Failure
N	=	Number of Items Tested
P_a	=	Probability of Acceptance
P	=	Fraction Defective
r	=	Number of Failures
T	=	Test Time
X^2	=	Chi Square
$\sum_{r_1}^{r_2}$	=	(Sigma) Summation from r_1 to r_2
!	=	Factorial sign 0! = 1
R	=	Reliability

INTRODUCTION

Components in missiles, launchers and other tactical weapons are subject to failure during their useful life. It is frequently required to calculate confidence boundaries from life test data or from attribute tests.

Two methods are given below to allow rapid and easy computation of these estimates - rearranged Poisson tables and nomographs. The tables are arranged in such a way as to give the Poisson parameter (a) for confidence levels ranging from 2% to 99.9% for up to 50 failures. The nomographs encompass two distinct, limited, ranges (2 -30% and 70 - 98%) of confidence for up to 45 failures. They solve the equations for

$$a = \frac{T}{MTBF} \quad \text{or } a = NP$$

By simply using a straight edge connecting line A (a) with B (T or N) and reading the answer on line C (MTBF, P, R).

THEORY

The tables are based on the Poisson Equation

$$P_a = \sum_{r=0}^{r} \frac{a^r e^{-a}}{r!} = 1\text{-}C$$

$$\text{where } a = \frac{T}{MTBF} \qquad \text{or } a = NP$$

This methodology can be used to obtain approximate confidence boundaries for reliability from attribute test data and also O-C curves by using the Poisson approximation for the binomial equation, letting

$$a = \frac{T}{MTBF} \qquad NP = N(1\text{-}R) = a$$

It should be pointed out that Chi-square tables are normally used to calculate the confidence boundaries by the equation

$$MTBF \gtrsim \frac{2T}{X^2\,(2r + 2,\ 1\text{-}C)}$$

Which is equivalent to the Poisson method used here.

Since the Poisson distribution is only an approximation for the Binomial-not very accurate for small sample sizes-a nomograph published by Western Electric Company could be used.

See appendix for a description of the computer program used to calculate the tables.

USER'S MANUAL

The following examples will show how to use the nomograph and the tables:

EXAMPLE 1:

Problem: A sample of 100 was randomly selected from a population whose reliability we wish to estimate. There were three failures. It is desired to find the lower 80% confidence limit.

Solution: Using the nomograph (Figure 1b) go to 80% confidence on the baseline, follow the vertical to three failures - go parallel to the baseline over to the reference line A, mark this point, connect it with 100 on line (B) and extend to line C marked "fraction defective" - read 0.055. The dark line is the worked solution. The confidence limit can also be determined using the Poisson tables and the formula.

$$P = a/N$$

where

a = Poisson parameter

N = number of sample units

P = fraction defective

Using Poisson table 1, sheet 2 read 5.5153 for 80% confidence and 3 failures.

$$P \quad \frac{a}{N} \quad \frac{5.5153}{100} \quad 0.055153$$

This means the reliability is 94.5% with 80% confidence. The "Binominal Reliability Tables"* give .94554 for the reliability. This compares favorably with our 0.05515.

EXAMPLE 2:

Problem: An equipment should have a Mean Time Between Failure (MTBF) of 10,000 hours, but is acceptable if 90% have a MTBF of 2000 hours or more (β = 0.1). If the actual MTBF is 10,000 hours the producer does not want it rejected more than

*Binominal reliability table, NAVWEPS Rep. 8090 (NOTS TP 3140)

10% (α = 0.1) of the times. To do this find the correct test time, draw an O-C curve, and also determine what the O-C curve would look if the test time and the allowable failures were tripled.

<u>Solution:</u> Using table I, sheets 1 and 2 find the test time for 10% confidence for 10,000 hours MTBF and 90% for 2000 Hours MTBF. (a = T/MTBF)

FAILURES	Table I, Sheet I 10% Conf a	T a x 10,000	Table I, Sheet 3 90% Conf a	T a x 2000
0	.1056	1056	2.307	4614
1	.5309	5309	3.8901	7780
2	1.1020	11020	5.3229	10646
3	1.7439	17439	6.6812	13362
4	2.4319	24319	7.9937	15588
5	3.1512	31512	9.2751	18550
6	3.8946	38946	10.5325	21064

This table shows that the test time most closely satisfying both conditions is 11,000 hours with two failures.

The O-C curves for 2 and 6 failures are shown on the next page. This example is illustrated in the "Pocket Handbook on Reliability,"* Section 5, pp. 52-63. It should be noted that the calculated points close to the 2000 and 10,000 hour MTBF lines coincide with the values given in Figure 5-4, p. 58.

*"Pocket Handbook on Reliability" by J.K. Byers, and H.A. Weibe, USAAVSCOM Tech Rep. 77-16.

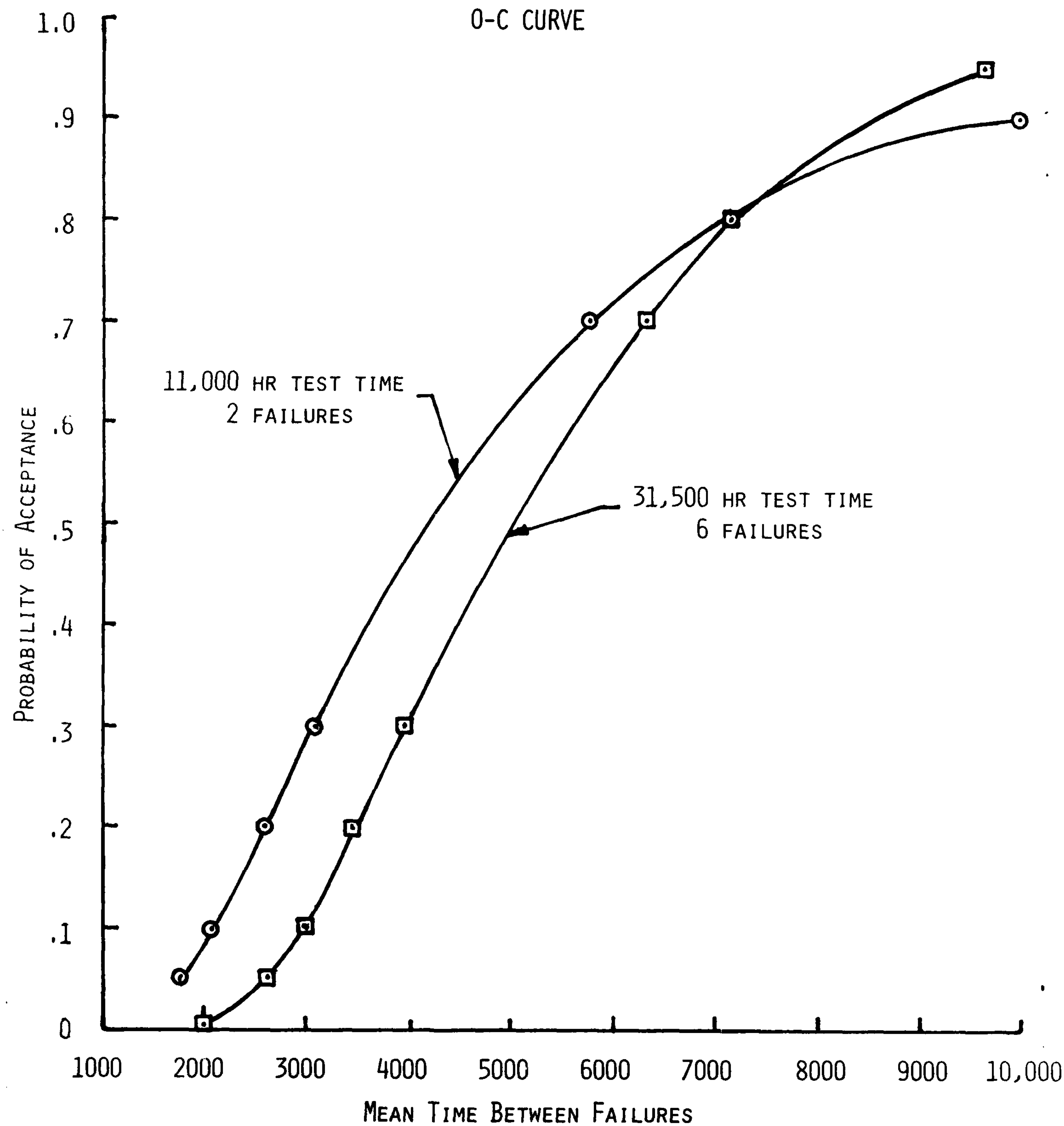
Use the nomograph for 70, 80, 90 and 95% confidence.

Pa	Confidence (2 failures)	MTBF at 11,000	Tables
.3	70	3050	3042
.2	80	2550	2570
.1	90	2050	2066
.05	95	1750	1797

Use the Tables:

Pa	Confidence (2 failures)	MTBF at 11,000
.9	10	9981
.8	20	7161
.7	30	5748

Pa	Confidence (6 failures)	MTBF at 31,500
.3	70	3880
.2	80	3470
.1	90	3000
.05	95	2650
.9	10	8088
.8	20	6655
.7	30	5822
.005	99.5	2013


O-C CURVE
Probability of Acceptance
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
11,000 HR TEST TIME
2 FAILURES
31,500 HR TEST TIME
6 FAILURES
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000
Mean Time Between Failures

EXAMPLE 3:

The "Pocket Handbook on Reliability" on pages 40-42 illustrates a method for calculating the MTBF for certain confidence limits. It gives the lower 95% confidence limit for 1836 hours and 3226 hours of testing with 4 and 7 failures, respectively, as 200.6 and 245 hours. Using the confidence, the test time, and the number of failures and Nomograph Figure 1c gives these answers by going from 95% confidence, 4 failures parallel to the baseline to line A. Connect the point on line A with 1836 on line B for total test time, extend and read 200 MTBF on line C. Use the same method for 3226 hours and 7 failures.

EXAMPLE 4:

Problem: A piece of equipment was tested for 10 hours and had 3 failures. What is the expected MTBF at 80% confidence.

Solution: Go to 80% confidence on the baseline of Nomograph Figure 1a follow the vertical to 3 failures, go parallel to the baseline over to line A, mark this point, connect with 10 on line B, extend to line C, and 1.8 on the right side of li..e C.

APPENDIX

A computer program is used to calculate the probability based upon the following equations:

$$P_r = \sum_{r=0}^{r=50} \frac{a^r e^{-a}}{r!} \qquad a = \frac{T}{MTBF}$$

$$a = NP$$

When P_r = probability of success

r = number of failures

$\sum_{r=0}^{r=50}$ = sigma summation from 0 to r

a = Poisson parameter

T = total test time

MTBF = Mean Time Between Failure

N = number of items tested

P = fraction defective

The calculational scheme is developed making the following expansion:

$$P_r = \frac{a^0 e^{-a}}{0!} + \frac{a^1 e^{-a}}{1!} + \frac{a^2 e^{-a}}{2!} + \cdots + \frac{a^r e^{-a}}{r!}$$

removing the common term e^{-a}, the equation then becomes

$$P_r = e^{-a}\left\{\frac{a^0}{0!} + \frac{a}{1} + \left(\frac{a}{1}\right)\left(\frac{a}{2}\right) + \left(\frac{a}{1}\right)\left(\frac{a}{2}\right)\left(\frac{a}{3}\right) + \cdots + \frac{a^r}{r!}\right\}$$

and using $D_0 = \frac{a^0}{0!} = 1$

$$D_1 = D_0\left(\frac{a}{1}\right)$$

$$D_2 = D_1\left(\frac{a}{2}\right)$$

$$D_3 = D_2\left(\frac{a}{3}\right)$$

.

.

$$D_r = D_{r-1}\left(\frac{a}{r}\right)$$

the equation becomes

$$P_r = e^{-a}(D_0 + D_1 + D_2 + \ldots + D_{r-1} + D_r)$$

With this equation a table of probabilities for a from 0.01 to 100 in increments of 0.1 0.1 and for failures from 0 to 50 in increments of 1 is created as shown in Table A.

It is then possible to enter Table A with a failure and a probability and interpolate for a. The results are shown in Table B. It is from the use of Table B that the nomographs are created. For direct sampling a is the product of the number of items in the sample and the fraction of failures (i.e., a = NP). For time testing a is the test time divided by the MTBF (i.e., a = T/MTBF).

The nomographs do not show probability but "confidence." Confidence is 1.0 minus the probability of failure. This means if the probability of failure is only .1 that the MTBF will be lower than the specified amount then the confidence will be .9 that the MTBF will be higher than the specified amount.

The points on the left side of the nomograph give the numerical values of a. This value then is used to calculate the total test time (T) or MTBF in the formula $a = \frac{T}{MTBF}$ (or the fraction defective in the formula a = NP).

Since the Poisson distribution is only an approximation for the binomial - not very accurate at small sample sizes - a nomograph of the binomial published by Western Electric Company could be used. Also, Sandia Corporation, in April 1960, published "A Confidence Limit Computer" based on the binomial distribution.

Table C shows the input data. The computer program is attached as Table 1.

PROBABILITY

r / a	Ø	1	2	...	48	49	50
0.1	0.9048	0.9953	0.9998		1.000	1.000	1.000
0.2	0.8187	0.9825	0.8678		1.000	1.000	1.000
0.3	0.7408	0.9631	0.9964		1.000	1.000	1.000

TABLE A
Probabilities for Lambda Versus Failures

P / r	0.98	0.95	0.05	0.02
0	0.0127	0.0476	2.9959	3.9126
1	0.2128	0.3531	4.7448	5.8349
.				
.				
.				
49	36.5707	38.9644	62.1713	65.5711
50	37.4261	39.8484	63.2872	66.7158

TABLE B
Lambdas for Failures Versus Probabilities

SAMPLE INPUT

0.98	0.95	0.90	0.80			
0.70	0.60	0.50	0.40	0.30		
0.20	0.10	0.05	0.02			
0.01	0.005	0.001	0.0005	0.0001	0.00005	0.00001
-1.0						

TABLE C

FAILURES	PROB	.98000	.95000	.90000	.80000
	%CONF	2.00000	5.00000	10.00000	20.00000
	ALPHA	.02000	.05000	.10000	.20000
0		.0127	.0476	.1056	.2240
1		.2128	.3531	.5309	.8242
2		.5643	.8167	1.1020	1.5347
3		1.0150	1.3650	1.7439	2.2967
4		1.5279	1.9690	2.4319	3.0894
5		2.0884	2.6125	3.1512	3.9036
6		2.6832	3.2848	3.8946	4.7334
7		3.3068	3.9802	4.6555	5.5758
8		3.9518	4.6951	5.4320	6.4282
9		4.6177	5.4248	6.2209	7.2891
10		5.3000	6.1683	7.0204	8.1567
11		5.9957	6.9237	7.8289	9.0307
12		6.7041	7.6893	8.6455	9.9100
13		7.4231	8.4633	9.4692	10.7939
14		8.1522	9.2457	10.2996	11.6819
15		8.8911	10.0354	11.1349	12.5737
16		9.6369	10.8316	11.9758	13.4689
17		10.3912	11.6338	12.8214	14.3673
18		11.1512	12.4414	13.6712	15.2685
19		11.9183	13.2541	14.5250	16.1723
20		12.6911	14.0716	15.3825	17.0786
21		13.4687	14.8936	16.2432	17.9871
22		14.2516	15.7192	17.1075	18.8977
23		15.0393	16.5486	17.9743	19.8102
24		15.8314	17.3818	18.8440	20.7245
25		16.6276	18.2183	19.7165	21.6405
26		17.4277	19.0577	20.5914	22.5582
27		18.2314	19.9006	21.4684	23.4775
28		19.0386	20.7455	22.3477	24.3983
29		19.8491	21.5939	23.2292	25.3202
30		20.6629	22.4441	24.1127	26.2435
31		21.4797	23.2974	24.9981	27.1681
32		22.2996	24.1523	25.8851	28.0940
33		23.1215	25.0100	26.7738	29.0208
34		23.9462	25.8693	27.6642	29.9487
35		24.7737	26.7308	28.5562	30.8778
36		25.6037	27.5945	29.4497	31.8079
37		26.4354	28.4595	30.3447	32.7387
38		27.2697	29.3267	31.2410	33.6706
39		28.1063	30.1957	32.1387	34.6034
40		28.9443	31.0658	33.0376	35.5369
41		29.7849	31.9378	33.9378	36.4713
42		30.6270	32.8115	34.8392	37.4066
43		31.4711	33.6865	35.7417	38.3424
44		32.3171	34.5627	36.6453	39.2791
45		33.1645	35.4405	37.5500	40.2165
46		34.0139	36.3197	38.4557	41.1545
47		34.8645	37.2003	39.3625	42.0933
48		35.7179	38.0817	40.2702	43.0326
49		36.5707	38.9644	41.1789	43.9726
50		37.4261	39.8484	42.0885	44.9132

TABLE I SHEET 1

FAILURES						
	PROB	.70000	.60000	.50000	.40000	.30000
	%CONF	30.00000	40.00000	50.00000	60.00000	70.00000
	ALPHA	.30000	.40000			
0		.3579	.5113	.6935	.9170	1.2042
1		1.0974	1.3767	1.6787	2.0228	2.4399
2		1.9138	2.2852	2.6743	3.1055	3.6159
3		2.7636	3.2114	3.6722	4.1755	4.7627
4		3.6335	4.1478	4.6711	5.2369	5.8905
5		4.5171	5.0910	5.6703	6.2920	7.0056
6		5.4107	6.0393	6.6697	7.3429	8.1112
7		6.3121	6.9914	7.6693	8.3898	9.2090
8		7.2198	7.9466	8.6690	9.4341	10.3007
9		8.1328	8.9044	9.6688	10.4758	11.3874
10		9.0502	9.8644	10.6686	11.5154	12.4697
11		9.9715	10.8262	11.6684	12.5533	13.5482
12		10.8962	11.7897	12.6683	13.5895	14.6233
13		11.8236	12.7546	13.6682	14.6244	15.6955
14		12.7538	13.7208	14.6681	15.6581	16.7653
15		13.6863	14.6881	15.6680	16.6905	17.8326
16		14.6209	15.6565	16.6679	17.7220	18.8977
17		15.5575	16.6258	17.6678	18.7526	19.9612
18		16.4960	17.5960	18.6678	19.7822	21.0227
19		17.4359	18.5670	19.6677	20.8111	22.0825
20		18.3774	19.5387	20.6677	21.8394	23.1410
21		19.3203	20.5111	21.6676	22.8669	24.1979
22		20.2645	21.4841	22.6676	23.8937	25.2537
23		21.2100	22.4577	23.6675	24.9201	26.3081
24		22.1566	23.4319	24.6675	25.9459	27.3615
25		23.1043	24.4066	25.6675	26.9711	28.4137
26		24.0529	25.3817	26.6674	27.9958	29.4651
27		25.0026	26.3574	27.6674	29.0202	30.5153
28		25.9531	27.3335	28.6674	30.0441	31.5648
29		26.9045	28.3100	29.6674	31.0675	32.6133
30		27.8567	29.2869	30.6673	32.0905	33.6611
31		28.8097	30.2641	31.6673	33.1132	34.7080
32		29.7634	31.2418	32.6673	34.1356	35.7544
33		30.7179	32.2197	33.6673	35.1576	36.7998
34		31.6729	33.1981	34.6673	36.1792	37.8448
35		32.6287	34.1766	35.6672	37.2005	38.8889
36		33.5851	35.1555	36.6672	38.2216	39.9326
37		34.5420	36.1347	37.6672	39.2424	40.9756
38		35.4996	37.1142	38.6672	40.2629	42.0180
39		36.4576	38.0940	39.6672	41.2832	43.0600
40		37.4162	39.0739	40.6672	42.3031	44.1012
41		38.3753	40.0542	41.6672	43.3229	45.1422
42		39.3349	41.0346	42.6671	44.3424	46.1826
43		40.2950	42.0153	43.6671	45.3617	47.2225
44		41.2555	42.9963	44.6671	46.3807	48.2620
45		42.2165	43.9774	45.6671	47.3996	49.3009
46		43.1778	44.9587	46.6671	48.4182	50.3396
47		44.1396	45.9402	47.6671	49.4367	51.3778
48		45.1019	46.9220	48.6671	50.4550	52.4155
49		46.0644	47.9039	49.6671	51.4730	53.4530
50		47.0274	48.8860	50.6671	52.4909	54.4899

TABLE I SHEET 2

FAILURES					
	PROB	.20000	.10000	.05000	.02000
	%CONF	80.00000	90.00000	95.00000	98.00000
	BETA	0.2	0.1	0.05	0.02
0		1.6099	2.3027	2.9959	3.9126
1		2.9945	3.8901	4.7448	5.8349
2		4.2795	5.3229	6.2959	7.5171
3		5.5153	6.6812	7.7544	9.0846
4		6.7213	7.9937	9.1542	10.5809
5		7.9061	9.2751	10.5133	12.0276
6		9.0757	10.5325	11.8430	13.4370
7		10.2329	11.7713	13.1487	14.8170
8		11.3800	12.9948	14.4352	16.1736
9		12.5190	14.2061	15.7053	17.5100
10		13.6511	15.4068	16.9627	18.8302
11		14.7769	16.5982	18.2077	20.1357
12		15.8973	17.7818	19.4430	21.4284
13		17.0134	18.9583	20.6690	22.7096
14		18.1253	20.1283	21.8867	23.9812
15		19.2334	21.2925	23.0972	25.2439
16		20.3381	22.4519	24.3012	26.4977
17		21.4396	23.6062	25.4992	27.7449
18		22.5384	24.7566	26.6919	28.9846
19		23.6345	25.9026	27.8795	30.2183
20		24.7282	27.0454	29.0624	31.4464
21		25.8196	28.1844	30.2408	32.6687
22		26.9089	29.3205	31.4150	33.8859
23		27.9963	30.4536	32.5856	35.0984
24		29.0820	31.5837	33.7528	36.3067
25		30.1660	32.7113	34.9163	37.5109
26		31.2483	33.8367	36.0769	38.7110
27		32.3290	34.9595	37.2345	39.9075
28		33.4082	36.0801	38.3890	41.1003
29		34.4861	37.1985	39.5413	42.2901
30		35.5628	38.3152	40.6906	43.4767
31		36.6382	39.4300	41.8379	44.6603
32		37.7123	40.5430	42.9826	45.8410
33		38.7854	41.6542	44.1253	47.0187
34		39.8575	42.7638	45.2659	48.1939
35		40.9284	43.8717	46.4042	49.3669
36		41.9983	44.9782	47.5410	50.5373
37		43.0675	46.0832	48.6757	51.7051
38		44.1356	47.1869	49.8086	52.8712
39		45.2027	48.2892	50.9400	54.0350
40		46.2692	49.3902	52.0696	55.1964
41		47.3348	50.4901	53.1974	56.3565
42		48.3995	51.5887	54.3242	57.5141
43		49.4637	52.6862	55.4493	58.6703
44		50.5270	53.7826	56.5729	59.8245
45		51.5895	54.8780	57.6949	60.9770
46		52.6516	55.9723	58.8160	62.1279
47		53.7128	57.0656	59.9357	63.2771
48		54.7735	58.1579	61.0541	64.4249
49		55.8335	59.2492	62.1713	65.5711
50		56.8928	60.3396	63.2872	66.7158

TABLE I SHEET 3

FAILURES	PROB	.01000	.00500	.00100	.00050	.00010	.00005
	%CONF	99.00000	99.50000	99.90000	99.95000	99.99000	99.99500
	BETA	0.01	0.005	0.001	0.0005	0.0001	0.00005
0		4.6054	5.2984	6.9081	7.6009	9.2108	9.9037
1		6.6394	7.4310	9.2344	9.9987	11.7575	12.5070
2		8.4062	9.2745	11.2297	12.0524	13.9290	14.7257
3		10.0460	10.9781	13.0631	13.9349	15.9143	16.7519
4		11.6048	12.5943	14.7943	15.7102	17.7826	18.6563
5		13.1087	14.1506	16.4556	17.4110	19.5680	20.4745
6		14.5712	15.6604	18.0624	19.0555	21.2900	22.2279
7		16.0000	17.1343	19.6268	20.6549	22.9633	23.9298
8		17.4027	18.5787	21.1570	22.2173	24.5949	25.5891
9		18.7835	19.9985	22.6581	23.7500	26.1932	27.2135
10		20.1453	21.3979	24.1346	25.2563	27.7630	28.8077
11		21.4901	22.7797	25.5896	26.7401	29.3067	30.3762
12		22.8212	24.1456	27.0265	28.2035	30.8293	31.9213
13		24.1397	25.4968	28.4468	29.6507	32.3319	33.4464
14		25.4466	26.8365	29.8522	31.0813	33.8167	34.9530
15		26.7434	28.1646	31.2442	32.4978	35.2860	36.4431
16		28.0309	29.4823	32.6241	33.9018	36.7413	37.9181
17		29.3098	30.7908	33.9928	35.2942	38.1829	39.3797
18		30.5814	32.0909	35.3521	36.6761	39.6127	40.8289
19		31.8459	33.3833	36.7010	38.0479	41.0317	42.2665
20		33.1032	34.6685	38.0425	39.4100	42.4403	43.6929
21		34.3552	35.9468	39.3752	40.7644	43.8393	45.1098
22		35.6007	37.2186	40.7002	42.1101	45.2292	46.5176
23		36.8418	38.4846	42.0189	43.4492	46.6107	47.9164
24		38.0773	39.7455	43.3309	44.7806	47.9847	49.3070
25		39.3080	41.0004	44.6366	46.1055	49.3516	50.6901
26		40.5348	42.2514	45.9364	47.4248	50.7108	52.0663
27		41.7571	43.4969	47.2307	48.7380	52.0642	53.4353
28		42.9754	44.7389	48.5197	50.0456	53.4107	54.7973
29		44.1899	45.9762	49.8037	51.3479	54.7521	56.1542
30		45.4098	47.2095	51.0834	52.6453	56.0871	57.5042
31		46.6086	48.4395	52.3587	53.9378	57.4172	58.8497
32		47.8130	49.6656	53.6294	55.2258	58.7424	60.1890
33		49.0144	50.8881	54.8957	56.5093	60.0624	61.5237
34		50.2128	52.1076	56.1589	57.7890	61.3777	62.8536
35		51.4083	53.3241	57.4178	59.0649	62.6885	64.1785
36		52.6010	54.5376	58.6735	60.3368	63.9951	65.4988
37		53.7914	55.7481	59.9255	61.6046	65.2977	66.8154
38		54.9793	56.9558	61.1743	62.8697	66.5964	68.1278
39		56.1647	58.1609	62.4199	64.1311	67.8914	69.4361
40		57.3478	59.3634	63.6626	65.3890	69.1828	70.7406
41		58.5286	60.5635	64.9019	66.6443	70.4707	72.0414
42		59.7070	61.7612	66.1391	67.8959	71.7551	73.3387
43		60.8838	62.9567	67.3731	69.1453	73.0362	74.6325
44		62.0585	64.1499	68.6042	70.3913	74.3139	75.9230
45		63.2311	65.3409	69.8335	71.6351	75.5887	77.2102
46		64.4016	66.5299	71.0599	72.8760	76.8609	78.4944
47		65.5709	67.7167	72.2837	74.1142	78.1299	79.7759
48		66.7382	68.9016	73.5053	75.3504	79.3958	81.0545
49		67.9034	70.0849	74.7249	76.5837	80.6598	82.3300
50		69.0675	71.2664	75.9423	77.8149	81.9206	83.6024

TABLE I SHEET 4

```
      PROGRAM POISSN
     $( INPUT, OUTPUT, TAPE5=INPUT, TAPE6=OUTPUT )
C
C     CODED FOR RHODEN BY RADKE ON 25MAR82.
C
      REAL ANS(51,8)
      REAL D(51)
      REAL DELTA
      REAL FACTOR
      REAL LAMBDA(1000)
      REAL LTAB(1000)
      REAL PROB(1000,51)
      REAL PTAB(1000)
      REAL XP(8)
C
      INTEGER I
      INTEGER J
      INTEGER K
      INTEGER L
      INTEGER LUI
      INTEGER LUO
      INTEGER ML
      INTEGER MP
      INTEGER MR
      INTEGER NERR
      INTEGER NF
      INTEGER NP
C
C     EXTERNAL EXP
C     EXTERNAL ITERP1
C     EXTERNAL FLOAT
C
      DATA LUI/5/
      DATA LUO/6/
      DATA ML/1000/
      DATA MR/51/
      DATA MP/8/
C
      DELTA = 0.1
      DO 134 L=1,ML
      LAMBDA(L) = FLOAT(L)*DELTA
      FACTOR = EXP(-LAMBDA(L))
      D(1) = 1.0
      PROB(L,1) = FACTOR
      DO 132 J=2,MR
      D(J) = D(J-1)*LAMBDA(L)/FLOAT(J-1)
      PROB(L,J) = PROB(L,J-1) + FACTOR*D(J)
  132 CONTINUE
  134 CONTINUE
C
```

```
  111 CONTINUE
C
      READ  (LUI,5111) (XP(I),I=1,MP)
 5111 FORMAT(8E10.3)
C
      IF( XP(1).LT.0.0 )      GO TO 999
      DO 121 I=1,MP
      IF( XP(I).EQ.0.0 )      GO TO 122
  121 CONTINUE
      NP = MP
      GO TO 123
  122 CONTINUE
      NP = I - 1
      IF( NP.EQ.0 )      GO TO 999
  123 CONTINUE
      DO 142 L=1,ML
      J = ML - L + 1
      LTAB(L) = LAMBDA(J)
  142 CONTINUE
      DO 148 K=1,MR
      DO 144 L=1,ML
      J = ML - L + 1
      PTAB(L) = PROB(J,K)
  144 CONTINUE
      DO 146 L=1,NP
      CALL ITERP1 (XP(L), PTAB, LTAB, ML, 2, ANS(K,L), NERR)
      IF( NERR.EQ.0 )      GO TO 145
      NF = K - 1
C
      WRITE (LUO,6145) NERR, NF, XP(L), ANS(K,L)
 6145 FORMAT(1X,12HERROR NUMBER,I3,5X,14HFAILURE NUMBER,I3,5X,
     $ 11HPROBABILITY,F10.5,5X,3HANS,F10.5)
C
  145 CONTINUE
  146 CONTINUE
  148 CONTINUE
```

```
C
      LURD = 5
      LUWT = 6
      WRITE (LUWT,6181)
 6181 FORMAT(1H1,2X,1HF)
      WRITE (LUWT,6182) (XP(I),I=1,NP)
 6182 FORMAT(3X,10HA    PROB ,8(1X,F9.5))
      WRITE (LUWT,6183)
 6183 FORMAT(3X ,1HI)
      WRITE (LUWT,6184)
 6184 FORMAT(3X ,1HL)
      DO 152 I=1,NP
      XP(I) = (1.0 - XP(I))*100.0
  152 CONTINUE
      WRITE (LUWT,6185) (XP(I),I=1,NP)
 6185 FORMAT(3X,10HU    %CONF,8(1X,F9.5))
      WRITE (LUWT,6186)
 6186 FORMAT(3X ,1HR)
      WRITE (LUWT,6187)
 6187 FORMAT(3X ,1HF)
      DO 154 I=1,NP
      XP(I) = XP(I)/100.0
  154 CONTINUE
      WRITE (LUWT,6188) (XP(I),I=1,NP)
 6188 FORMAT(3X,10HS    ALPHA,8(1X,F9.5))
      WRITE (LUWT,6193)
 6193 FORMAT(1H0)
C
      DO 192 K=1,MR
      NF = K - 1
C
      WRITE (LUO,6194) NF, (ANS(K,L),L=1,NP)
 6194 FORMAT(1X,I3,8X,8(1X,F9.4))
C
  192 CONTINUE
C
      GO TO 111
C
  999 CONTINUE
      STOP
      END
```

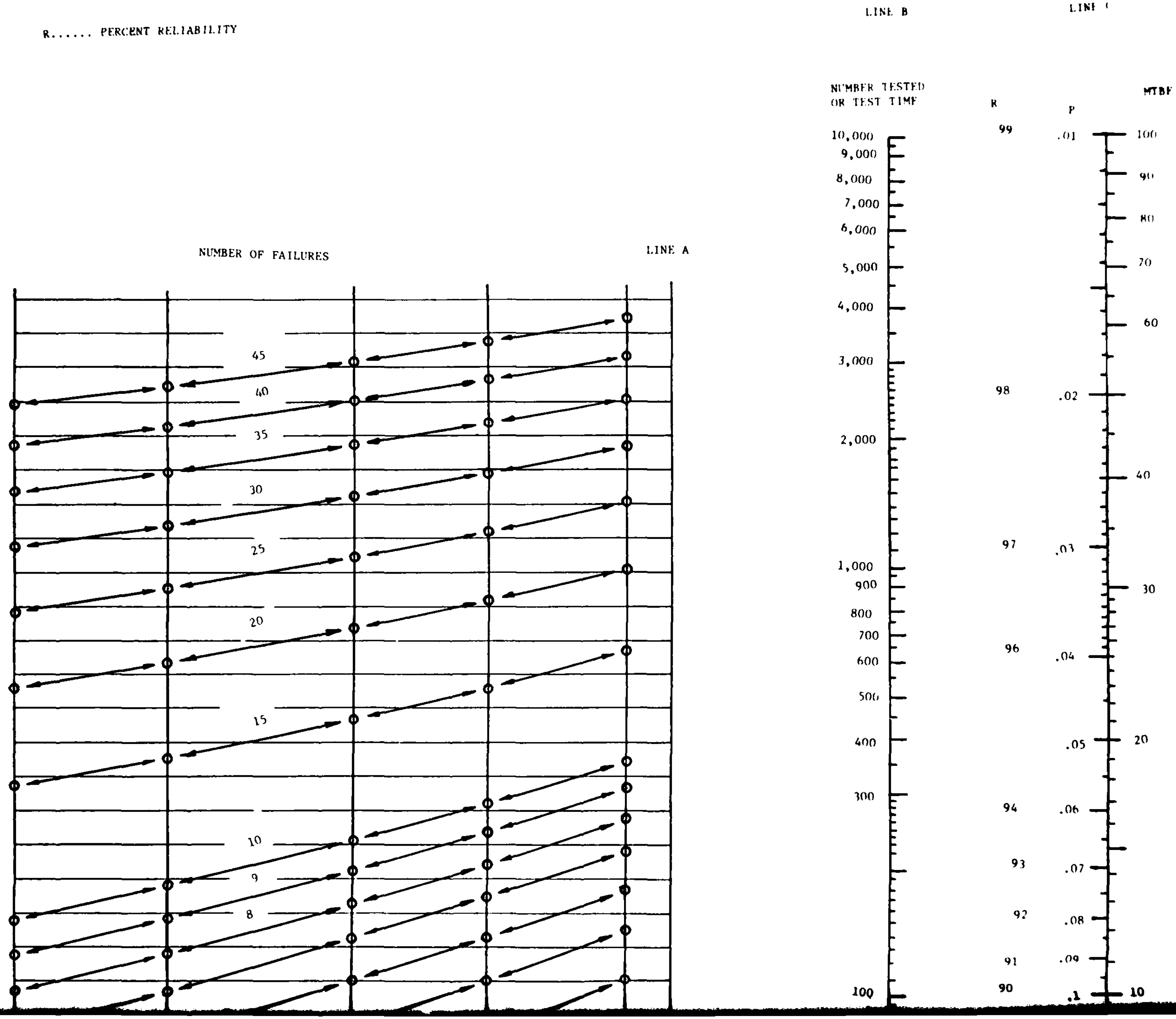
```
      SUBROUTINE ITERP1
     $(X,XT,YT,NX,NN,Y,IER)
C
C     CODED BY ROBERT RADKE/DRSMI-RKA ON 31MAR82
C
C
C         INPUT
C           X   THE INDEPENDENT VARIABLE VALUE
C           XT  THE TABLE OF INDEPENDENT VARIABLE VALUES
C               MUST BE IN ASCENDING ORDER
C           YT  THE TABLE OF DEPENDENT VARIABLE VALUES YT(I) = F(XT(I))
C           NX  THE NUMBER OF POINTS IN XT
C           NN  THE NUMBER OF POINTS USED IN THE INTEROLATING POLYNOMIAL
C
C         OUTPUT
C           Y   THE INTERPOLATED DEPENDENT VARIABLE VALUE Y=F(X)
C           IER THE ERROR CODE WHERE
C               = 0 IF XT(1) .LE. X .LE. XT(NX)
C               = 1 IF X .LT. XT(1)
C               = 2 IF X .GT. XT(NX)
C
C
      REAL XT(NX)
      REAL YT(NX)
      REAL X
      REAL Y
      REAL P
C
      INTEGER L
      INTEGER R
      INTEGER M
      INTEGER D
      INTEGER NX
      INTEGER NN
      INTEGER IER
      INTEGER NP
      INTFGER IH
      INTEGER I
      INTEGER J
      INTEGER K
```

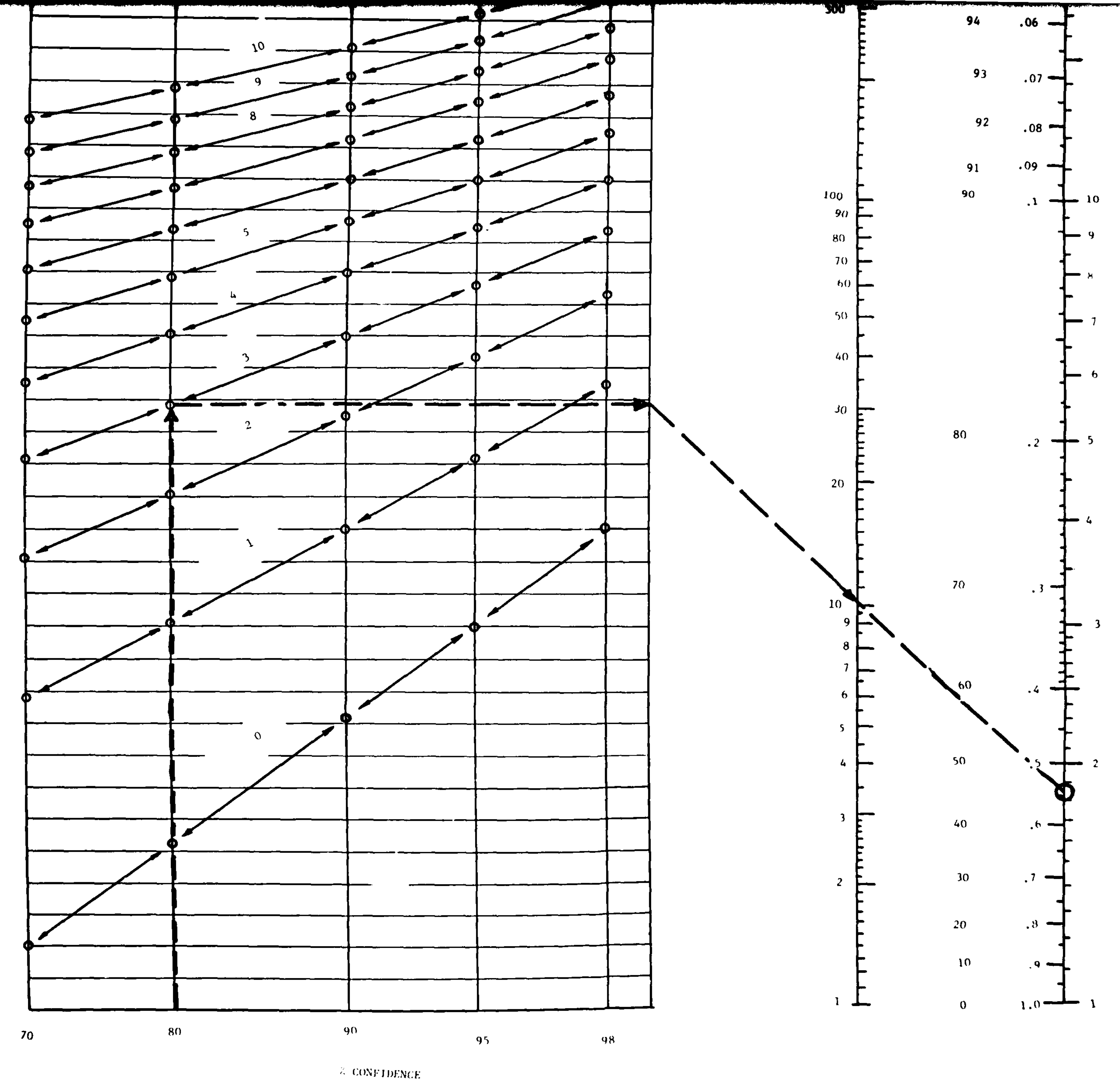
```
C
C          ENSURE THAT THE NUMBER OF POINTS IN THE INTERPOLATING POLYNOM
C                IS NO GREATER THAN THE NUMBER OF POINTS IN THE TABLE
C
      IF( NX.LT.NN )      GO TO 112
      NP = NN
      GO TO 113
  112 CONTINUE
      NP = NX
  113 CONTINUE
C
C          CHECK FOR X OFF THE LOWER END OF THE TABLE
C
      IF( X.NE.XT( 1) )      GO TO 121
      Y = YT( 1)
      IER = 0
      GO TO 999
  121 CONTINUE
      IF( X.GT.XT( 1) )      GO TO 122
C
C                X IS OFF THE LOWER END
C                    MAKE Y HAVE THE VALUE OF THE LOWER END
C                    RAISE THE ERROR FLAG
      Y = YT( 1)
      IER = 1
      GO TO 999
C
C          CHECK FOR X OFF THE UPPER END OF THE TABLE
C
  122 CONTINUE
      IF( X.NE.XT(NX) )      GO TO 123
      Y = YT(NX)
      IER = 0
      GO TO 999
  123 CONTINUE
      IF( X.LT.XT(NX) )      GO TO 124
C
C                X IS OFF THE UPPER END
C                    MAKE Y HAVE THE VALUE OF THE UPPER END
C                    RAISE THE ERROR FLAG
      Y = YT(NX)
      IER = 2
      GO TO 999
  124 CONTINUE
      IER = 0
```

```
C
C           PERFORM A BINARY SEARCH TO LOCATE X IN XT
C
      L = 1
      R = NX
  131 CONTINUE
      M = (L + R)/2
      IF( X.NE.XT( M) )      GO TO 132
      Y = YT( M)
      GO TO 999
  132 CONTINUE
      IF( X.LT.XT( M) )      GO TO 133
      L = M
      GO TO 134
  133 CONTINUE
      R = M
  134 CONTINUE
      D = R - L
      IF( D.NE.1 )      GO TO 131
C
C           DETERMINE THE BEGINING(LEFT) AND ENDING(RIGHT) TABLE POSITIONS
C
      IH = NP/2
      K = IH + 1
      IF( K.GT.R )      GO TO 142
      I = R
      GO TO 143
  142 CONTINUE
      I = K
  143 CONTINUE
C
      K = I - IH + NP - 1
      IF( K.GT.NX )      GO TO 152
      L = I - IH
      R = L + NP - 1
      GO TO 154
  152 CONTINUE
      L = NX - NP + 1
      R = NX
  154 CONTINUE
C
C           EVALUATE THE INTERPOLATION POLYNOMIAL
C
      Y = 0.0
      DO 168 J=L,R
      P = 1.0
      DO 164 I=L,R
      IF( I.EQ.J )      GO TO 163
      P = P*(X - XT(I))/(XT(J) - XT(I))
  163 CONTINUE
  164 CONTINUE
      Y = Y + P*YT(J)
  168 CONTINUE
C
  999 CONTINUE
      RETURN
      END
```

P ..... PROBABILITY OF FAILURE

R...... PERCENT RELIABILITY




% CONFIDENCE
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80
90
95
98
0
1
2
3
4
5
8
9
10
300
100
90
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50
40
30
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10
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8
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6
5
4
3
2
1
94
93
92
91
90
80
70
60
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20
10
0
.06
.07
.08
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.1
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.8
.9
1.0

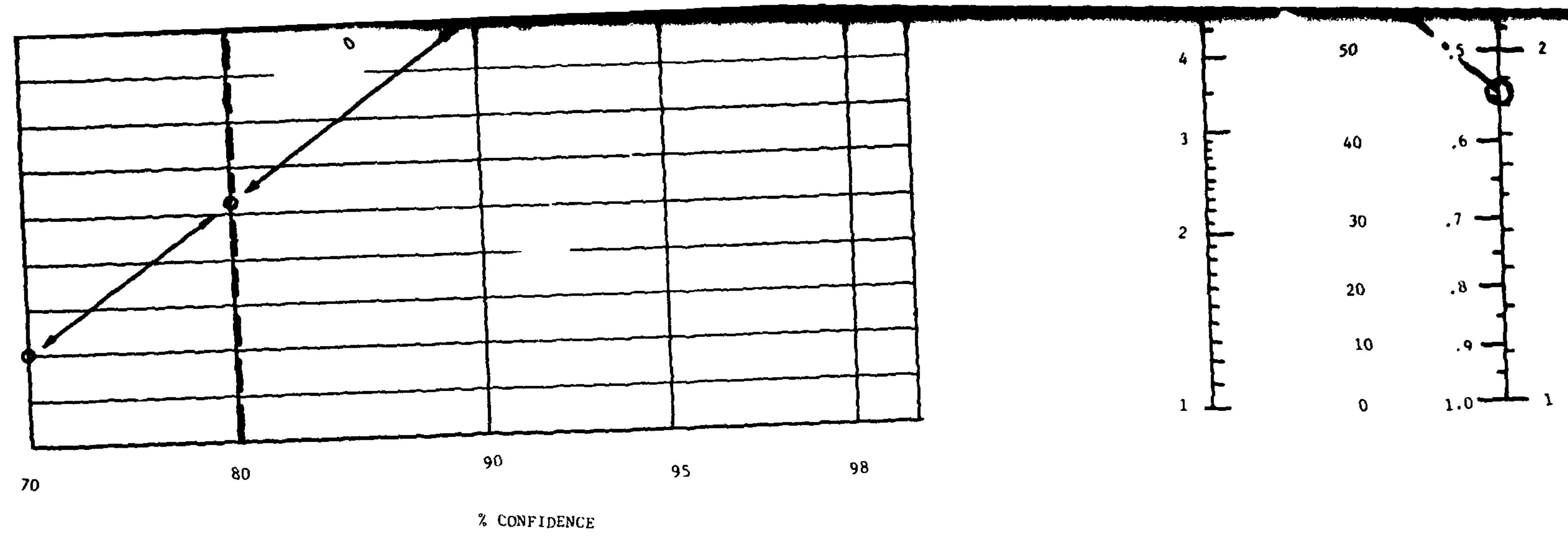
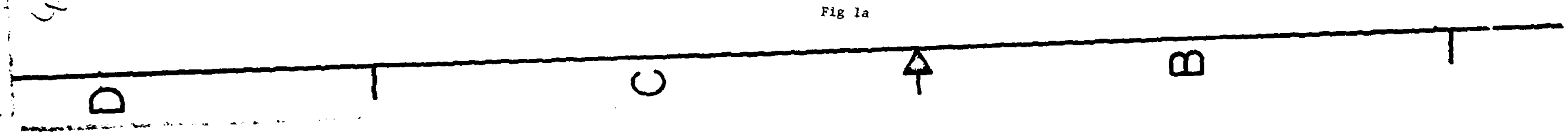
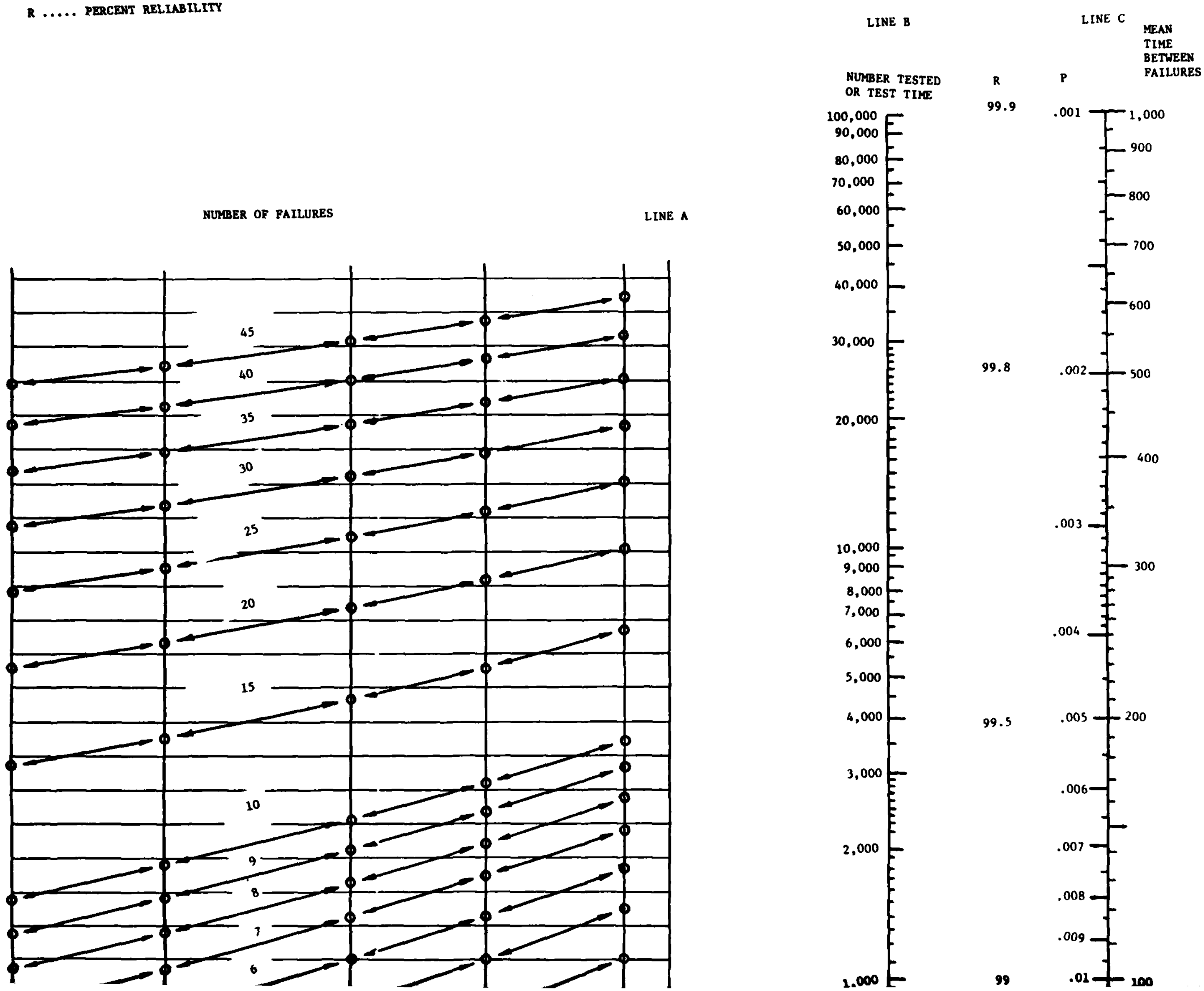


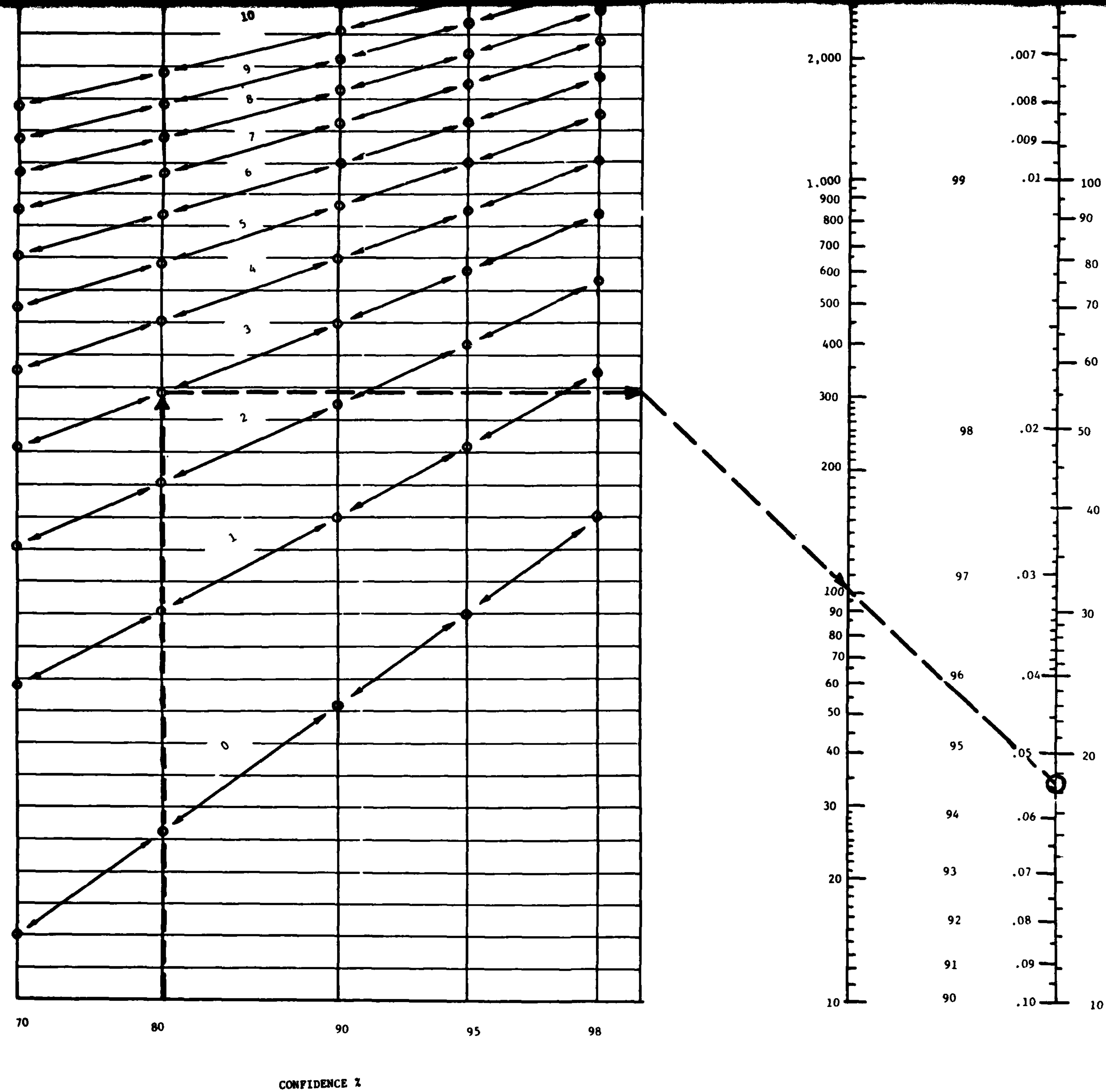
Fig 1a



P..... PROBABILITY OF FAILURE

R ..... PERCENT RELIABILITY





10
9
8
7
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5
4
3
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0
70
80
90
95
98
CONFIDENCE %
2,000
1,000
900
800
700
600
500
400
300
200
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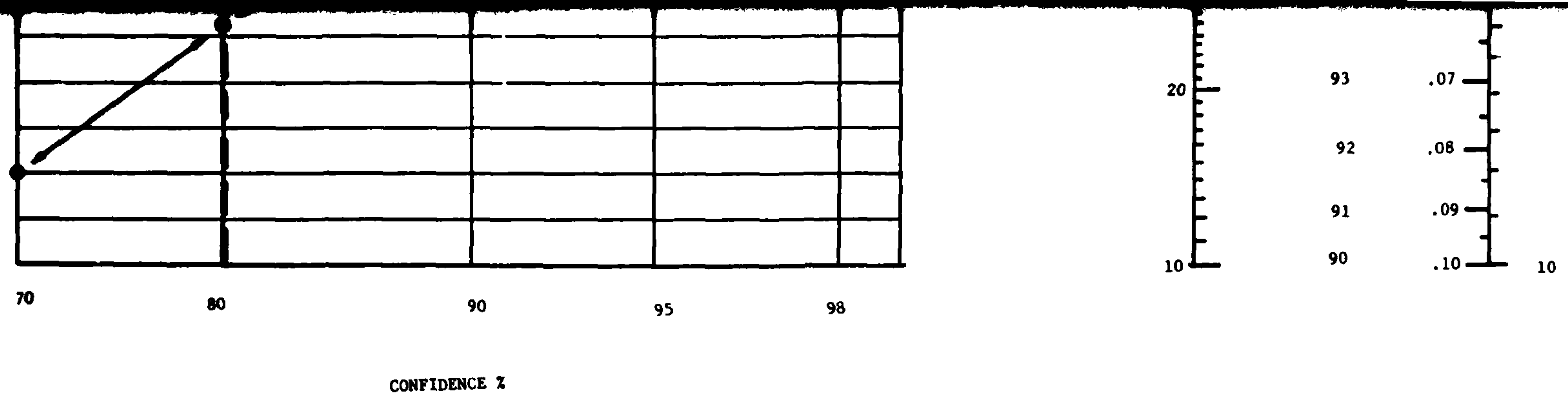
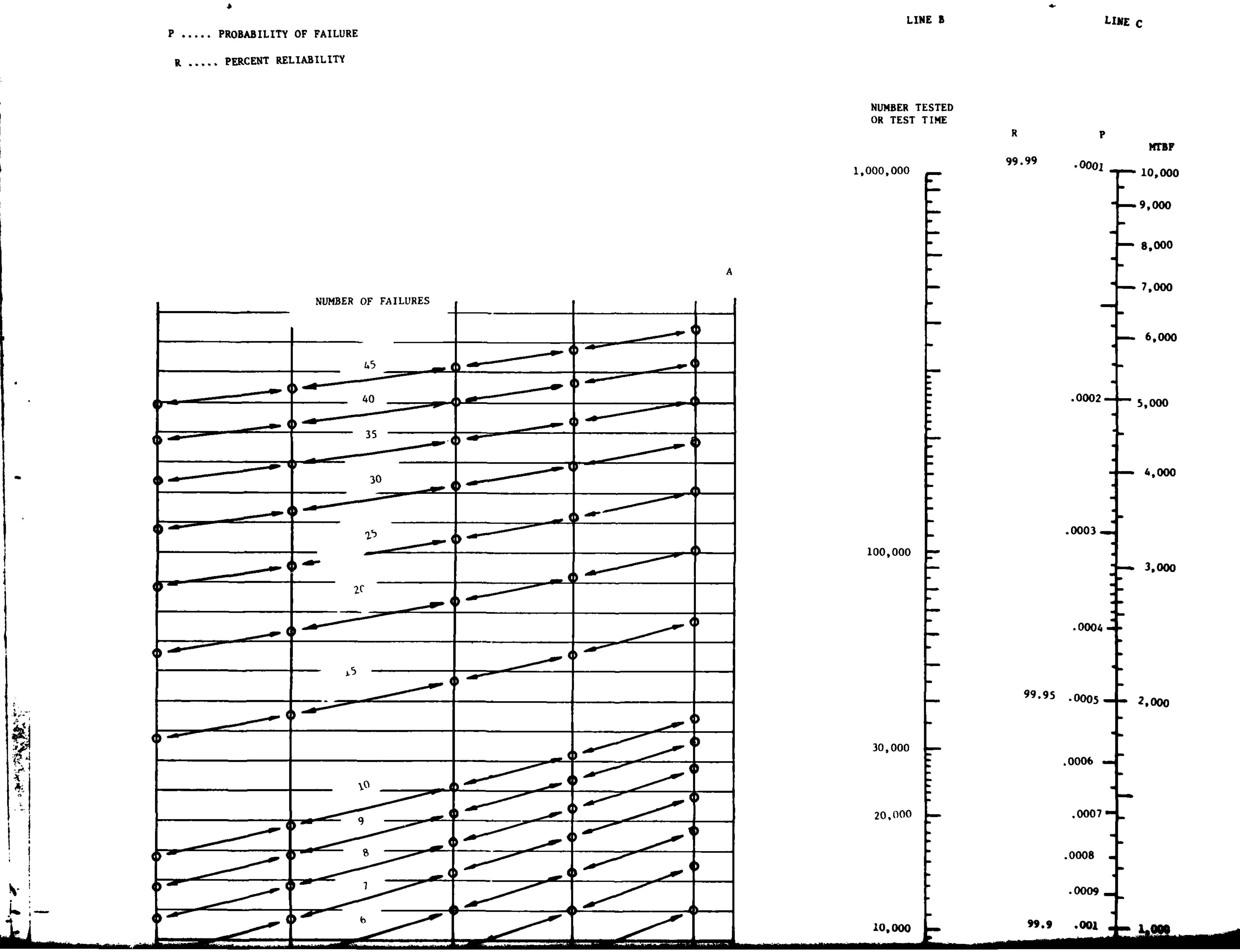


Fig 1b



P ..... PROBABILITY OF FAILURE
R ..... PERCENT RELIABILITY
LINE B
LINE C
NUMBER TESTED OR TEST TIME
R
P
MTBF
A
NUMBER OF FAILURES
45
40
35
30
25
20
15
10
9
8
7
6
1,000,000
100,000
30,000
20,000
10,000
99.99
99.95
99.9
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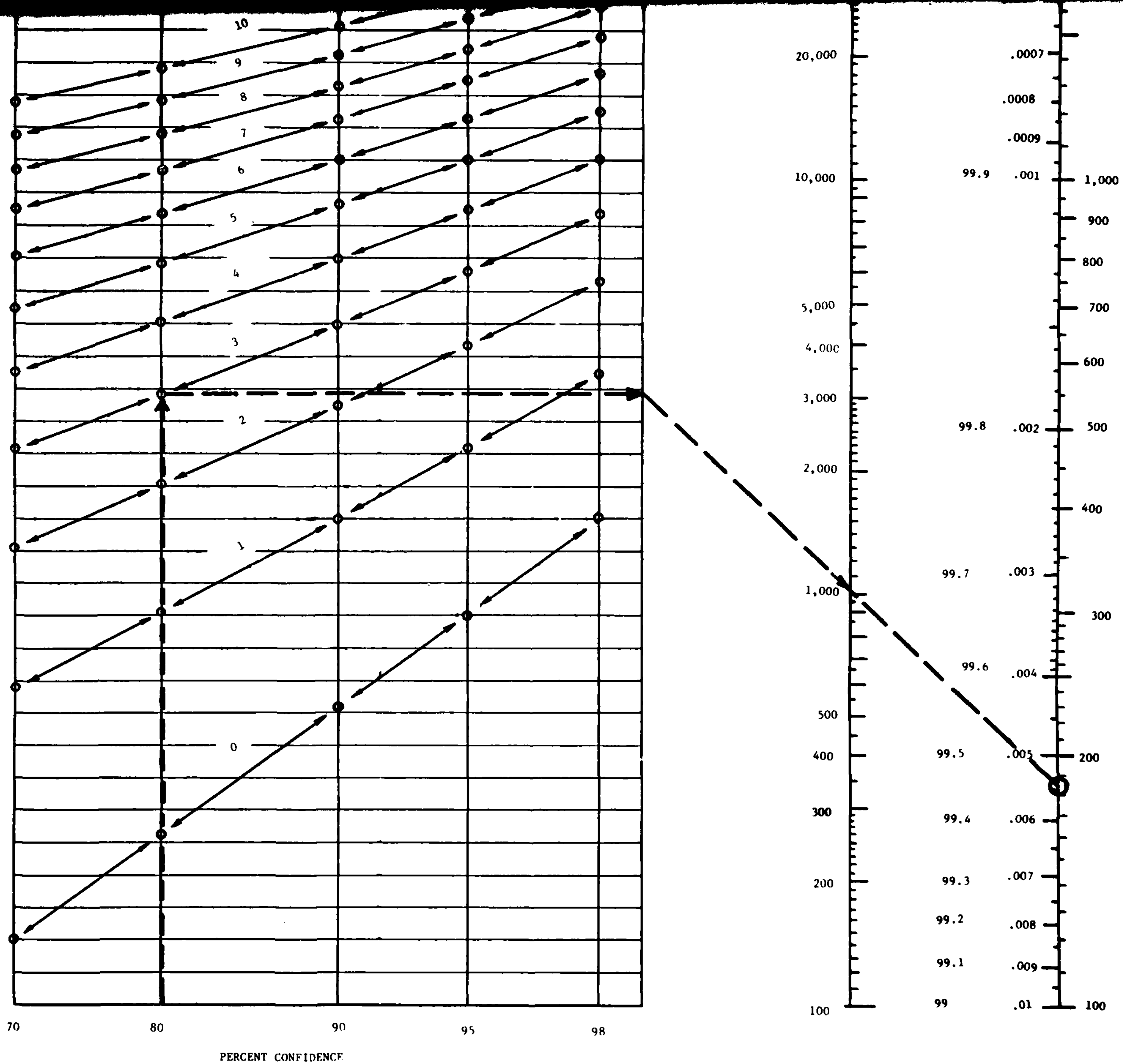
3,000
2,000
1,000


10
9
8
7
6
5
4
3
2
1
0
70
80
90
95
98
PERCENT CONFIDENCE
20,000
10,000
5,000
4,000
3,000
2,000
1,000
500
400
300
200
100
99.9
99.8
99.7
99.6
99.5
99.4
99.3
99.2
99.1
99
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.0008
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.002
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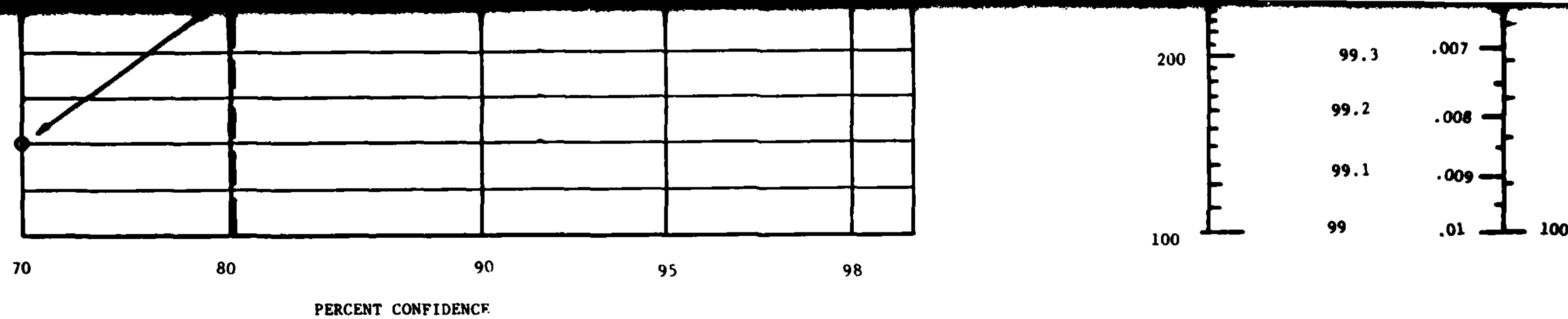
200
100

FIGURE 1c

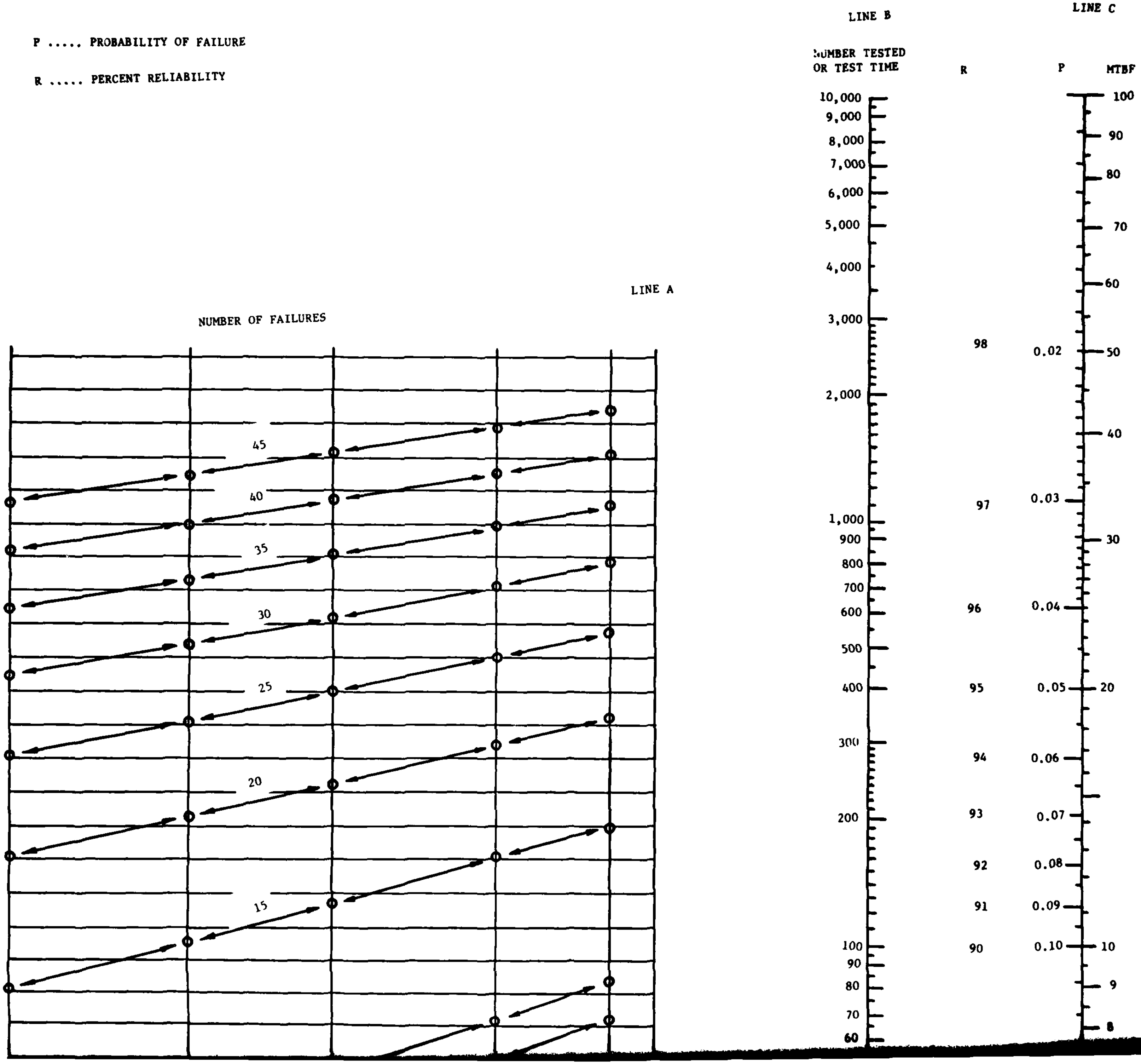


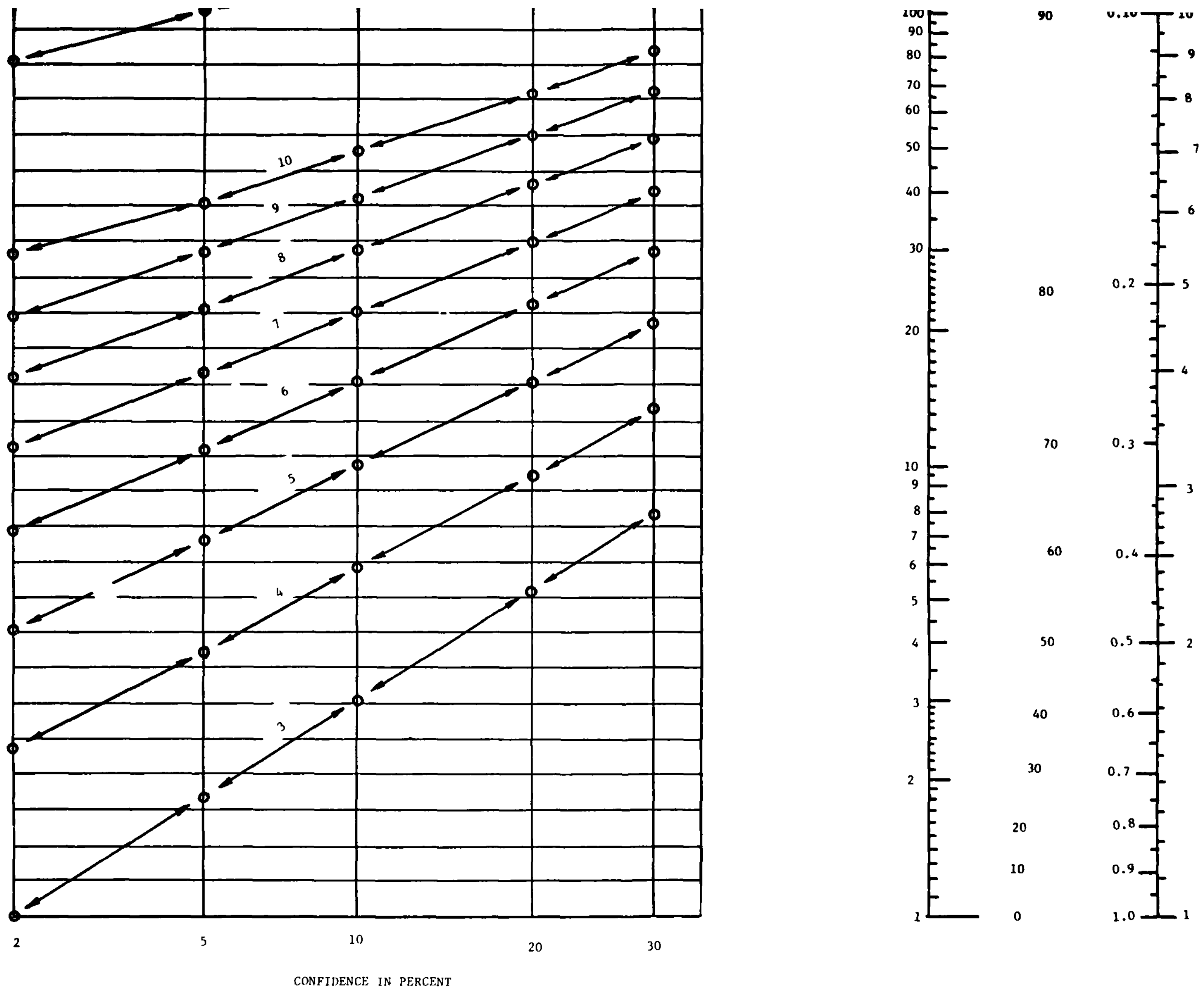
70
80
90
95
98
PERCENT CONFIDENCE
200
100
99.3
99.2
99.1
99
.007
.008
.009
.01
100

FIGURE 1c

P ..... PROBABILITY OF FAILURE

R ..... PERCENT RELIABILITY




10
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CONFIDENCE IN PERCENT
100
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20
10
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8
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6
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2
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1.0
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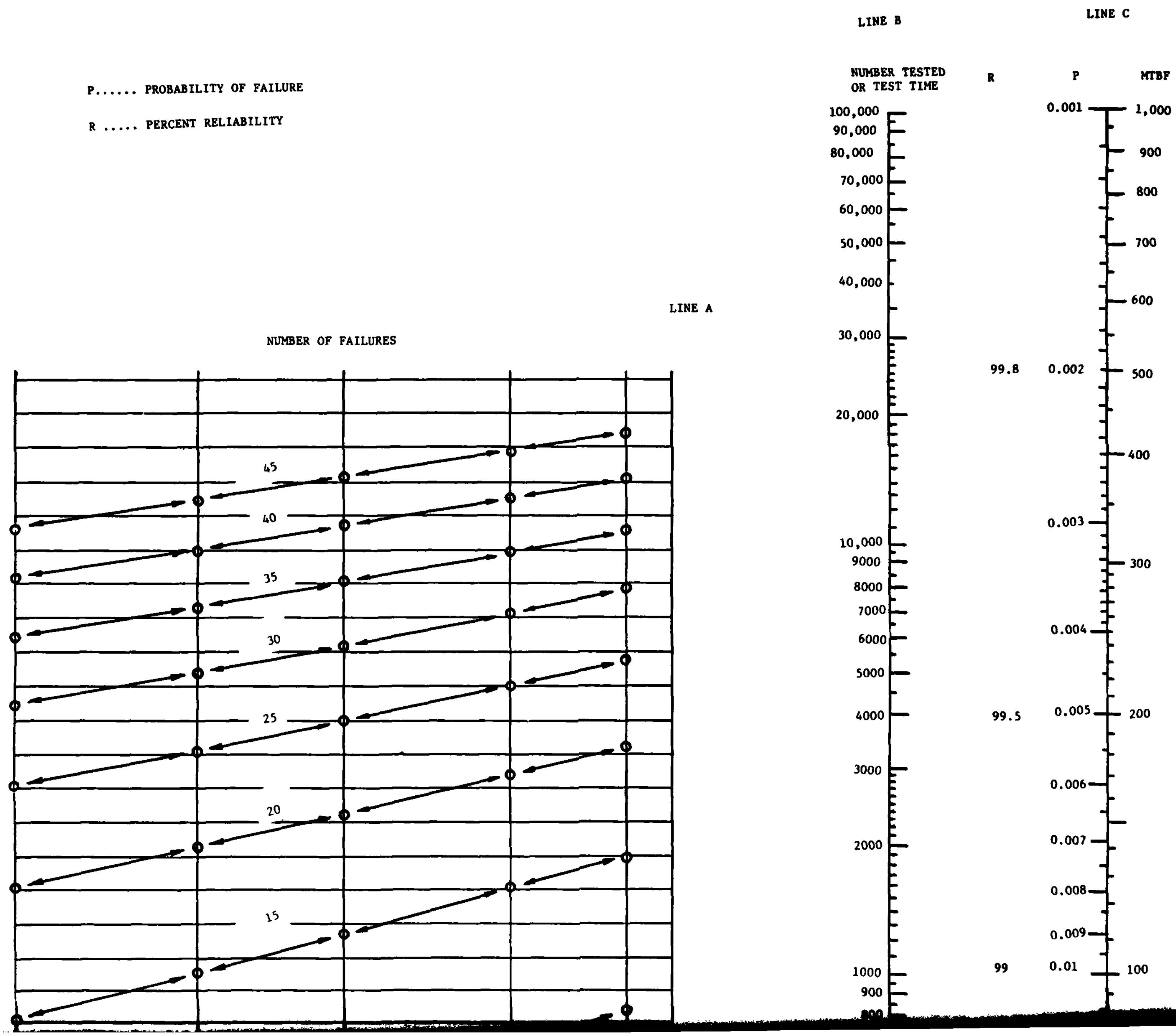
1

Fig 2a



P...... PROBABILITY OF FAILURE
R ..... PERCENT RELIABILITY
NUMBER OF FAILURES
45
40
35
30
25
20
15
LINE A
LINE B
NUMBER TESTED OR TEST TIME
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
LINE C
R
99.8
99.5
99
P
0.001
0.002
0.003
0.004
0.005
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0.009
0.01
MTBF
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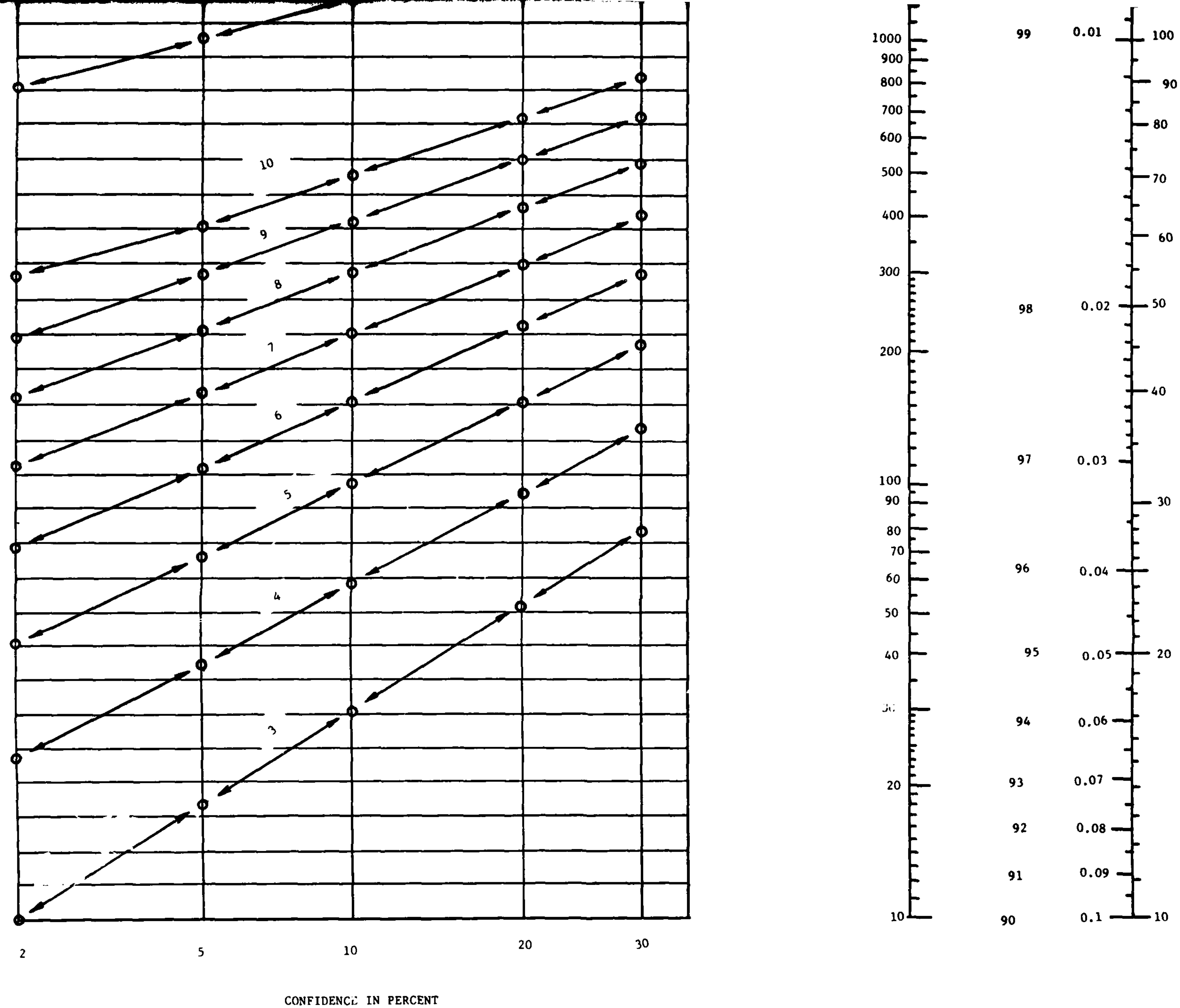
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CONFIDENCE IN PERCENT
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200
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0.02
0.03
0.04
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0.07
0.08
0.09
0.1
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30
20
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Fig 2b

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Commander White Sands Missile Range ATTN: STEWS-QA Whites Sands, NM 88002	2
Commander US Army Missile Command ATTN: DRSMI-RPR Redstone Arsenal, AL 35898	15

END

DATE